ADDITIONAL CHARACTERIZATION OF V-4Cr-4Ti AND MHD COATINGS EXPOSED TO FLOWING Li

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OBJECTIVE

Characterize specimens exposed to flowing Li in a thermal gradient to evaluate the effects on V-4Cr-4Ti and a multi-layer electrically-insulating coating needed to reduce the magneto hydrodynamic (MHD) force in the first wall of a lithium cooled blanket.

SUMMARY

Additional characterization is being performed on specimens exposed to flowing Li in a thermal gradient. These include 500°C tensile testing, measurement of changes in interstitial elements and characterization of the MHD coatings. To assist in the interpretation of these results, a group of specimens was annealed at 700°C for 2,350h in a quartz ampoule.

PROGRESS AND STATUS

Introduction

One critical unresolved issue for the vanadium-lithium blanket concept[1,2] (and any liquid metal concept) in a deuterium/tritium fueled fusion reactor[3,4] is the pressure drop associated with the magnetohydrodynamic (MHD) effect of a conducting liquid flowing across the magnetic field lines One proposed solution is to decouple the structural wall from the liquid metal with an electrically insulating coating or flow channel insert (FCI).[5] This coating application requires a thin, crack-free,[6] durable layer with a relatively high electrical resistance.[7] While a “self-healing” layer is possible in corrosion where a re-passivation can occur by the re-formation of a surface oxide, this concept is not applicable to functional (i.e. electrically resistant) coatings because a defect that shorts the coating is unlikely to “heal”. Therefore, a robust coating system or a FCI is needed for this application. Due to incompatibility between Li and virtually all candidate insulating oxides,[8-12] the current focus of the U.S. MHD coating program[10-12] is evaluating the compatibility of durable, multi-layer coatings[7,13] where a vanadium overlayer prevents direct contact between the insulating oxide layer and Li. This concept shifts the compatibility concern from the oxide layer to the thin vanadium overlayer. In order to verify that a thin, ~10µm, V layer is sufficiently compatible with Li to function in a long-term situation, a mono-metallic thermal convection loop was designed and built to expose specimens with thin V overlayers to flowing Li. The loop was operated at a peak temperature of ~700°C for 2,355h.[14,15] Initial characterization of the coatings and V-4Cr-4Ti specimens in the loop was previously reported.[15,16] Further progress with the characterization is reported here.

Experimental Procedure

Details of the loop exposure have been presented previously.[14-16] The specimens consisted of miniature tensile specimens (type SS-3: 25 x 4 x 0.9mm), tab specimens and specimens with a dual layer MHD coating.[14-16] Initial characterization of the specimens and tubing included metallographic cross-sections, hardness (Vickers, 300g) measurements, chemical analysis using combustion and inductively coupled plasma analysis, and room temperature and 500°C tensile testing at $10^{-3}s^{-1}$ strain rate. Selected specimens were examined using scanning electron microscopy (SEM) equipped with energy dispersive x-ray (EDX) analysis. The EB-PVD coatings were examined by SEM/EDX, contact profilometry and x-ray diffraction (XRD).

Results and Discussion

Sections of the V-4Cr-4Ti tubing were examined metallographically and the composition was analyzed. Figure 1 shows the tube hardness data at 6 locations compared to the initial hardness and the tab specimens at similar locations. The tubing started out with a lower hardness [17] compared to the tab specimens (which were not annealed prior to exposure in Li) but showed a similar trend in hardness after exposure, particularly at the highest temperature. Figure 2 shows the microstructure of the tubing after exposure at the bottom of the cold leg and the top of the hot leg. As expected, the grain size of the tubing from the hot section was larger but there was no obvious change in the microstructure of the surface layer in contact with Li.

Figure 3 compares the interstitial chemistry of the tube sections and tab specimens [15] after exposure. The initial O content in the tubing was somewhat higher than in the tab specimens which reflects the greater amount of O uptake during processing of the tubing. Both data sets show the same trends with the O content decreasing with temperature (due to O gettering by Li) and the N content increasing at the highest temperature (due to N gettering from the Li). Since the tubes were thicker than the tabs and only exposed to Li from one side, it is not surprising that the extent of O depletion or N uptake is not as great at the highest temperature. However, the C values show a different trend in the tube specimens. The C content decreased in the tube specimens while it increased slightly in the tab specimens. Decarburization was not expected at this temperature, and may reflect loss of C in the vacuum. The starting tube composition values are the average of 4 specimens.

The 500°C tensile tests to compliment the room temperature measurements are in progress. The vacuum tensile rig to conduct these measurements has been calibrated and the work is proceeding.

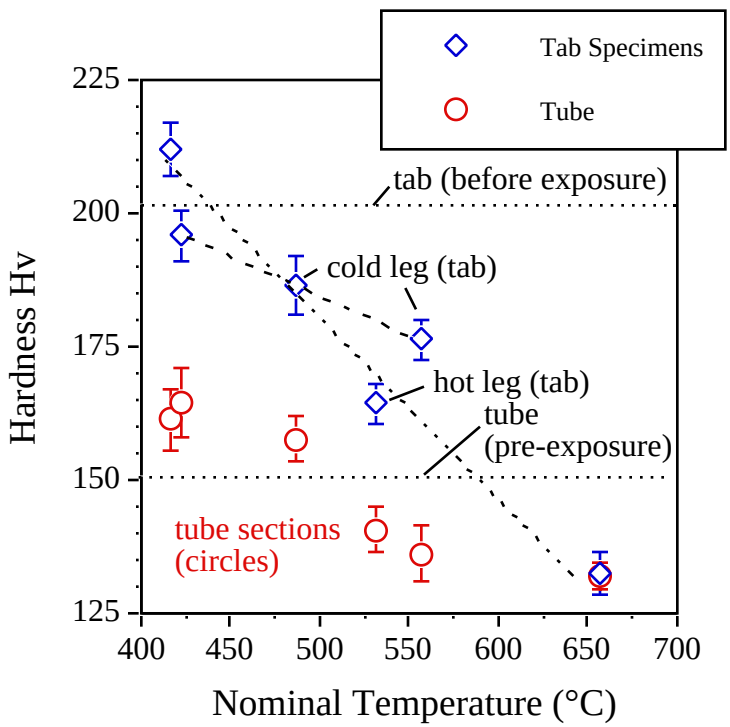

Figure 1. Average hardness measurements as a function of nominal exposure temperature along the hot and cold legs of the mono-metallic loop for tab specimens and tube specimens in similar locations.

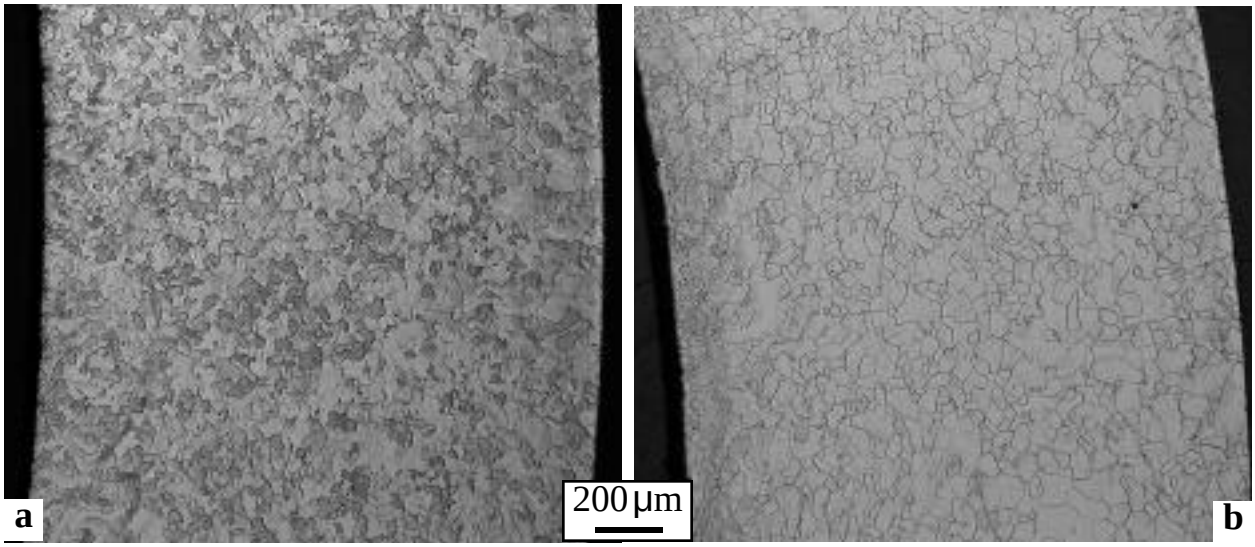

Figure 2. Light microscopy of the V-Cr-4Ti tubing in cross-section after exposure at (a) the bottom of the cold leg and (b) the top of the hot leg. The etchant was $60H_2O$-$30HNO_3$-10HF.

In order to assist in the interpretation of the results from Li exposure, a set of tensile, tab and one MHD coating were annealed for 2,350h at 700°C in a quartz ampoule. This provided a similar temperature as the hottest specimens in the loop without the Li exposure. Tensile specimens from that exposure did not change mass indicating no O uptake during the anneal. Initially, the microstructure of a tab specimen has been examined. Figure 4 shows the microstructure of the annealed tab compared to the tab specimen from the top of the hot leg. The grain growth and precipitate loss in the Li-exposed specimen was not evident in the annealed specimen. The curvature of the annealed MHD specimen was examined to

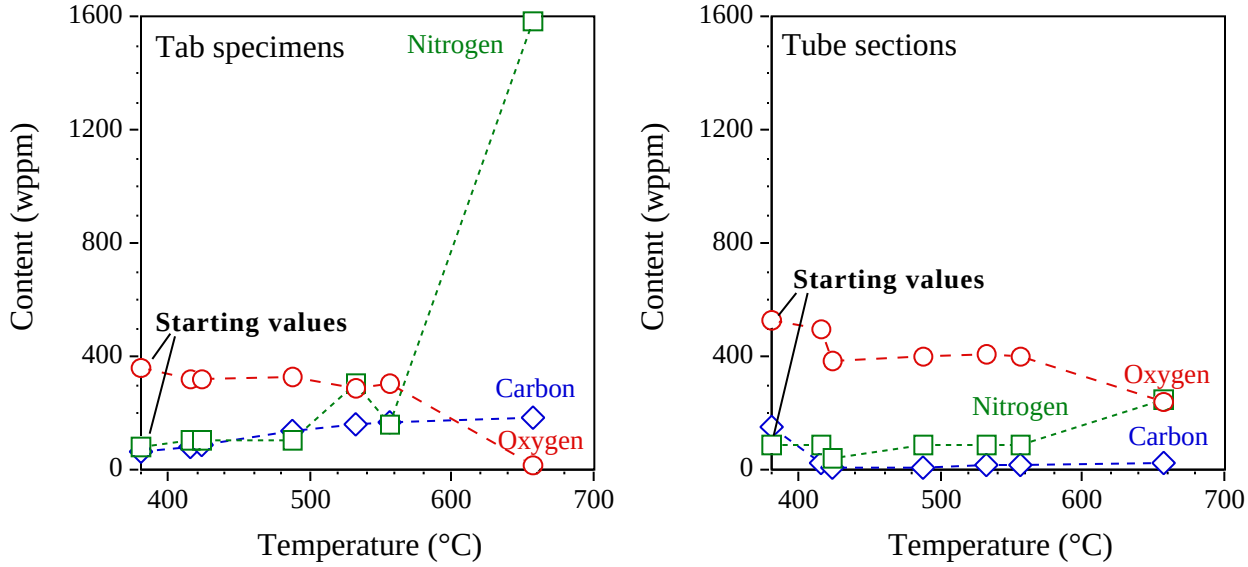

Figure 3. Measured O, C and N values for specimens at six locations in the loop (a) tab specimens and (b) tube specimens.

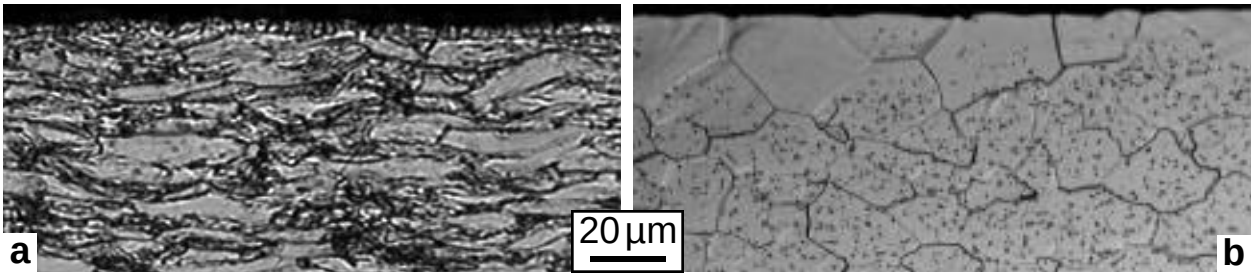

Figure 4. Light microscopy of cold-rolled V-4Cr-4Ti tab specimens (a) annealed for 2,350h at 700°C and (b) after exposure to flowing Li at the top of the hot leg (~655°C) where the surface grains appear depleted in precipitates.

compare to those exposed to Li. The annealed coating was from batch two and behaved similar to those coatings in the loop – the concave curvature increased after exposure. Batch 1 coatings which were exposed at the tops of the hot and cold legs, [16] changed curvature from concave to convex after exposure. The reason for the change in curvature has not been determined but likely reflects a change in the residual stress state of the coating and substrate.

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